IN-39
181378
20 P

NASA Technical Memorandum 106229

Hierarchical Nonlinear Behavior of Hot Composite Structures

P.L.N. Murthy and C.C. Chamis
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

and

S.N. Singhal
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

Prepared for the
First Joint SES, ASME, and ASCE Meeting
Charlottesville, Virginia, June 7–9, 1993

(NASA-TM-106229) HIERARCHICAL NONLINEAR BEHAVIOR OF HOT COMPOSITE STRUCTURES (NASA) 20 p

N94-14041

Unclas

G3/39 0189378

NASA

HIERARCHICAL NONLINEAR BEHAVIOR OF HOT COMPOSITE STRUCTURES

P.L.N. Murthy and C.C. Chamis
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

and

S.N. Singhal
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio 44142

SUMMARY

Hierarchical computational procedures are described to simulate the multiple scale thermal/mechanical behavior of high temperature metal matrix composites (HT–MMC) in the following three broad areas: (1) Behavior of HT–MMCs from micromechanics to laminate via METCAN (Metal Matrix Composite Analyzer), (2) tailoring of HT–MMC behavior for optimum specific performance via MMLT (Metal Matrix Laminate Analyzer), and (3) HT–MMC structural response for hot structural components via HITCAN (High Temperature Composite Analyzer). Representative results from each area are presented to illustrate the effectiveness of computational simulation procedures and accompanying computer codes. The sample case results show that METCAN can be used to simulate material behavior such as the entire creep span; MMLT can be used to concurrently tailor the fabrication process and the interphase layer for optimum performance such as minimum residual stresses; and HITCAN can be used to predict the structural behavior such as the deformed shape due to component fabrication. These codes constitute virtual portable desk-top test laboratories for characterizing HT–MMC laminates, tailoring the fabrication process, and qualifying structural components made from them.

INTRODUCTION

High temperature metal matrix composites (HT–MMCs) are emerging as materials with potentially high payoffs in aeronautic/aerospace structural applications. Realization of these payoffs depends on the parallel and synergistic development of: (1) a technology base for fabricating HT–MMC structural components, (2) experimental techniques for measuring their thermomechanical characteristics, and (3) computational methods for predicting their nonlinear behavior in prevailing service environments. There is, in fact, merit to the argument that the development of computational methods should precede the others because the structural integrity and durability of HT–MMCs can be computationally simulated and the potential payoffs for a specific application can be assessed, at least quantitatively. This makes it possible to minimize the time consuming and costly experimental effort that would otherwise be required in the absence of a predictive capability.

The computational simulation as discussed in the present paper differs from computer-aided solutions where traditional applied mathematics closed-form procedures are applied to reduce the governing equations. The computers are used to obtain limited and final answers without any information on the intermediate steps (Figure 1 for blade rotation). This figure also depicts the advantage of HT–MMCs versus homogeneous materials in nonlinear behavior. The permanent set upon unloading in HT–MMCs is significantly less than it is in homogeneous materials.

The computational simulation of HT–MMCs as presented here is based on (1) what constituents the composite materials are made from, (2) how their material behavior is manifested at their progressively interactive multiple scales including the effects of how they are made, (3) how the composite structures respond to service environments, (4) what governs their optimum behavior under a desirable set of design requirements, (5) solution of the fundamental governing field equations for all the participating variables by employing a computer as an integral part of the solution, and (6) simulating the evolution of the behavior or process as well as a specific structural response.

Because of multiple composite scales, a comprehensive understanding of the composite materials-behavior/structural-response can only be gained by (1) starting the simulation at the lowest material scale (fiber/matrix/interphase constituents), and (2) hierarchically carrying over the materials/structural effects through the progressive composite scales (constituents, ply, laminate) to the structure scale.

Recent research at NASA Lewis is directed towards the development of a hierarchical computational capability to predict the nonlinear behavior of HT–MMCs. This capability is in the form of stand-alone computer codes which are used to computationally simulate HT–MMC behavior in all its inherent hierarchical scales. The simulation starts with constituents/fabrication-process and proceeds to unfold the effects induced by the aggressive service loading environments at the structural scale. The structural scale response, along with the environmental effects, is then used to update the materials behavior at the constituent scale, thus accounting for all the interactive effects. Based on the fundamental physics of how the HT–MMC materials/structures behave, requisite computational procedures and corresponding computer codes have been developed to span the entire hierarchy inherent in these composites. The objective of the present paper is to (1) briefly describe these computational procedures/codes and (2) present illustrative results from their applications to demonstrate the effectiveness of hierarchical computational capability for simulating and tailoring the HT–MMC materials-behavior/structural-response including the fabrication effects.

HIERARCHICAL COMPUTATIONAL SIMULATION

The various composite scales involve micromechanics (intraply), macromechanics (interply), laminate (multiple plies), local region (plate type finite element), and structural component (assemblage or many finite elements). A computational simulation hierarchy of HT–MMCs is depicted schematically in Figure 2 where the computational capabilities, the corresponding computer codes, their interfacing, and specific objectives are summarized. The first set of codes, fundamental to the hot materials behavior, for the laminate-specific synthesis are METCAN (Metal Matrix Composite Analyzer) and CEMCAN (Ceramic Matrix Composite Analyzer). Reference 1 and 2 contain the implementation and demonstration of the formal procedures embedded in METCAN and CEMCAN, respectively. These codes differ in only the micromechanics, thus the current paper describes only the METCAN code and its applications. The materials behavior codes are integrated with an optimizer in order to tailor laminates and their fabrication process for specified HT–MMC properties.

The integrated materials-behavior/optimizer methodology is embedded into the computer code MMLT (Metal Matrix Laminate Tailoring—reference 3). The next level in the hierarchy is component-specific structural analysis which integrates METCAN with a finite element structural analysis code. It is embodied into the stand-alone portable computer code, HITCAN (High Temperature Composite Analyzer—reference 4). The final level in the hierarchy couples HITCAN with fluid and thermal mechanics codes and with an optimizer into another computer code, STAHYC (Structural Tailoring of Hypersonic Components—reference 5). Applications of STAHYC are not described in the present paper, due to limitation of page requirements.

Metal Matrix Composite Analyzer

The materials behavior of HT–MMCs from micromechanics to laminate is computationally simulated using the procedure embedded in METCAN. The structure of METCAN parallels the fabrication process of metal matrix composites. A typical fabrication process is schematically illustrated in Figure 3. The hierarchical simulation capability in METCAN is shown in Figure 4. METCAN starts from describing the material properties at the constituent (fiber/matrix/ interphase) scale and synthesizes the ply and laminate scale properties through composite micromechanics and laminate theories (left hand side of Figure 4). The laminate scale properties are used for the global structural analysis. The global structural response is then decomposed to the laminate, ply, and constituents scales (right hand side of Figure 4). METCAN forms the basis of the hierarchical simulation from the constituents scale to the structural component scale.

METCAN is capable of predicting the entire HT–MMC behavior domain, including the fabrication process by using mostly room temperature properties for the fiber, matrix, and interphase. Reference 6 includes a detailed description of the micromechanics used for representing the simulation at the constituent materials scale. Fundamental to the computational simulation in METCAN is the introduction of an innovative multifactor interaction model (MFIM) to represent the various nonlinearities and their mutual interactions in the constituents. The MFIM exploits a general-purpose form which is amenable to unlimited extensions for describing the interactive effects of all types of physical (metallurgical, chemical, mechanical, thermal, etc.) variables in one single equation. The equation form of the MFIM showing physical variables typical of the aeronautic/aerospace industry and reasons for its selection are summarized in Figure 5. A discussion on its ability to represent constituent material behavior and the subsequent influence of this behavior on the response of structural components made from HT–MMCs is presented in reference 7.

METCAN has been validated, verified, and calibrated for various HT–MMCs typical of aeronautic/aerospace industry. METCAN calibration for the comprehensive materials behavior requires only a few selected experimental tests. The minimum number of tests for calibrating METCAN for a specific HT–MMC are: (1) monotonic longitudinal tensile test; (2) monotonic transverse tensile test; (3) interlaminar shear creep rupture test; (4) thermal cyclic test of crossply laminate; and (5) mechanical cyclic test of crossply laminate. Once METCAN has been calibrated with these tests, the entire spectrum of HT–MMC behavior under various thermal and mechanical static and time-dependent loads can be predicted via METCAN. Obviously, the computational simulation via METCAN minimizes the costly and time consuming experimental effort that would otherwise be required in the absence of a predictive capability.

The validation and verification of the capabilities of METCAN with both 3-D finite element analysis predictions and experimental data have been an ongoing activity in-house. The details of such efforts are included in references 8, 9, and 10. METCAN has been verified for cyclic load behavior of HT–MMCs, as described in reference 8, where the influence of the interphase and limited comparisons with room temperature data are also described. METCAN simulation of in-situ behavior, how this can be used to interpret composite-measured behavior, and corresponding results for the development of an interphase between fiber and matrix, or weakening of the interfacial bond, are described in reference 9.

Recently, METCAN has been verified for long-term effects. As shown in Figure 6, METCAN simulates the three distinct creep regimes: primary, secondary, and tertiary. In order to obtain this excellent verification, it was necessary to include the processing history, i.e., cooling the composite from 815 °C to 21 °C. The important observation from these results is that the processing history must be included in order to accurately simulate the creep behavior of HT–MMCs. METCAN, as indicated earlier, is capable of simulating fabrication history effects. METCAN simulates the microstresses in the fiber and matrix during the creep process. The microstresses, corresponding to the composite creep behavior of Figure 6, are shown in Figure 7. As expected, the microstresses in the matrix peaked during the elastic (primary) region of the curve and then rapidly relaxed.

Those, in the fiber, continued to increase and leveled off when the matrix microstress relaxed completely. The entire stress was carried by the fiber during the secondary creep region for composites. The significant point is that METCAN describes the creep behavior at both micro and macro scales of HT–MMCs.

In essence, METCAN is a virtual portable desk-top laboratory for characterizing HT–MMCs at the ply and laminate scales for all the aforementioned effects. By using METCAN in combination with physical experiments, the characterization effort can be reduced to at most 10 percent of what would otherwise be required.

Metal Matrix Laminate Tailoring

While HT–MMCs are gaining popularity in the aeronautic/aerospace industry, one significant issue limiting the use of many HT–MMCs is the high residual thermal microstresses developed during the fabrication process. The residual thermal microstresses are due to the large temperature differential and the mismatch between the coefficients of thermal expansion of the fiber and matrix. The presence of residual microstresses typically degrades the mechanical performance of the composite and is primarily responsible for the reported poor thermomechanical fatigue endurance of many HT–MMCs. It is desirable, therefore, to explore possible ways to reduce, or alternatively control, the development of residual microstresses. It is possible to obtain reductions in residual stresses by tailoring the combinations of temperature and consolidation pressure during fabrication (reference 11). Moreover, the undesirable residual stresses can be further reduced by a combination of a compatible interphase layer (fiber coating) between the fiber and matrix coupled with the fabrication process optimization (reference 12).

MMLT is capable of concurrently tailoring the constituent (fiber/matrix/ interphase) materials characteristics and the fabrication process for an a priori specified HT–MMC behavior such as minimum residual stresses upon cool-down. MMLT is also capable of quantifying the strong coupling between the nonlinear thermomechanical response of MMCs during the fabrication process and the subsequent thermomechanical performance of the MMC in a typical service environment, resulting from the residual stresses and the nonlinearity of the composite.

MMLT simulates the thermomechanical response of the laminate with incremental nonlinear micromechanics and laminate mechanics theories. The structure of MMLT is shown in Figure 8. A typical thermomechanical life cycle of a MMC laminate from fabrication to failure at operational conditions, e.g., for hot engine sections, is shown in Figure 9.

Representative results from this work are reported herein to show the concept and usefulness of the methodology in achieving higher performance from HT–MMCs. A $[0/90]_s$ SiC/Ti15–3–3–3 (silicon carbide fiber and titanium matrix) laminate was used to demonstrate the effectiveness of MMLT. The Materials Division of NASA Lewis Research Center provided the current (untailored) fabrication process. The constituent properties and constraints imposed on microstresses and interphase thickness during the tailoring process can be found in reference 13. Initial interphase properties were assumed equivalent to the matrix properties. The initial interphase thickness was 12% of the fiber diameter and the fiber volume ratio of the composite was 0.4. The tailored fabrication process (temperature/ pressure) for the coupled interphase/fabrication optimization is shown in Figure 10. The consolidation pressure reached significantly higher pressures than the current process. The buildup of the microstresses is shown in Figure 11. The longitudinal microstresses, σ_{A11}, were reduced by 65 and 98% for the interphase and coupled interphase/fabrication-process tailoring cases, respectively. The transverse microstresses, σ_{A22}, were reduced by 77 and 99% for the interphase and coupled interphase/fabrication-process tailoring cases, respectively. The magnitude of the reduction in microstresses shows the importance of using a coupled interphase/fabrication-process tailoring via MMLT. MMLT is a virtual portable desk-top laboratory/factory for tailoring the fabrication process for HT–MMC laminates.

Hot Composite Structural Analyzer

The next level in the hierarchy after METCAN is the hot composite structural analyzer (HITCAN). HITCAN is a general purpose computer code for predicting global structural and local stress-strain response of arbitrarily oriented, multilayered high temperature metal matrix composite structures both at the constituent (fiber/matrix/interphase) and the structure scale. HITCAN combines METCAN with a NASA in-house finite element code, MHOST, and a dedicated mesh generator. The code is stand-alone and stream-lined for the thermal/structural analysis of hot metal matrix composite structures. A schematic of the code's structure is shown in figure 12. HITCAN is a modular code with an executive module controlling the input, analysis modules, database, nonlinear solvers, utility routines, and output. HITCAN's capabilities are summarized in Table 1. HITCAN is capable of simulating the behavior of all types of HT–MMC structural components (beam, plate, ring, curved panel, builtup structure) for all types of analyses (static, load stepping—multiple load steps accounting for degradation in material behavior from one load step to another, buckling, vibration) including fabrication-induced stresses, fiber degradation, and interphase. An extensive description of HITCAN including a variety of sample cases to illustrate its computational capabilities, can be found in reference 4.

The deformation of a MMC composite ring in which a slit is cut to measure residual stresses incurred during the fabrication process cool-down is included herein as a specific HITCAN example. The ring is made of SiC fibers and TiAl matrix with a fiber volume ratio of 0.50 and [0/90] laminate configuration. The ring geometry, finite element model, and the deformed shape are shown in Figure 13. This type of information is useful in deciphering the effect of fabrication process on the structural shape. The computational simulation capability thus predicts the fabricated shape of composite structures before actual fabrication. The code predictions can then be used in tailoring the fabrication process so as to obtain the desired fabricated shape. HITCAN may be considered as a virtual portable desk-top structural testing laboratory. Combination of HITCAN simulations with physical tests will expedite the component qualification process.

CONCLUSIONS

A hierarchical approach to computational simulation of hot metal matrix composites (HT–MMC) is described. The simulation starts at the lowest material scale (fiber/matrix/interphase constituents) and hierarchically carries the materials/structural effects through the progressive composite scales (constituents, ply, laminate) to the structure scale. The simulation is based on adapting a multifactor interaction model which is computationally efficient and is amenable to unlimited extensions for describing the interactive effects of all types of physical (metallurgical, chemical, mechanical, thermal, etc.) variables in one single equation.

The simulation methodology has been embedded in computer codes which can be used to simulate the complex behavior of hot structures made form HT–MMCs. Results form each code for select sample cases are included to illustrate the capabilities of each code.

The metal matrix composite analyzer (METCAN) describes the entire creep behavior at both micro and macro scales. The results show that the processing history must be included in order to accurately simulate the creep behavior of HT–MMCs. The metal matrix laminate tailoring (MMLT) code shows that concurrent tailoring of the fabrication process and interphase layer can significantly reduce the undesirable residual microstresses. The hot composite structural analyzer (HITCAN) is capable of predicting deformation in composites shapes during the fabrication process. Collectively, the results from these sample cases demonstrate that hierarchical computational simulation methods can be developed to effectively simulate the complex behavior of HT–MMCs. Verifications with experimental data confirm that micromechanics based hierarchical approaches (1) are fundamentally sound, (2) account for inherent attributes in the composite, (3) require few coupon characterization tests, (4) allow for early-on prototype design and fabrication, and (5) provide an effective assessment of fabrication quality. The corresponding computer codes can be viewed as virtual portable desk-top testing laboratories for HT–MMC laminate characterization and for HT–MMC structural component qualification.

REFERENCES

1. Hopkins, D.A., "Nonlinear Analysis of High-Temperature Multilayered Fiber Composite Structures—Turbine Blades," NASA TM–83754, 1984.
2. Murthy, P.L.N. and Chamis C.C., "Towards the Development of Micromechanics Equations for Ceramic Matrix Composites via Fiber Substructuring," NASA TM–106246, 1992.
3. Morel, M., Saravanos, D.A., and Murthy, P.L.N., "MMLT-Metal Matrix Laminate Tailoring User's Manual," NASA TM–106052, 1993.
4. Singhal, S.N., Lackney, J.J., Chamis, C.C., and Murthy, P.L.N., "Demonstration of Capabilities of High Temperature Composite Analyzer Code HITCAN," NASA TM–102560, 1990.
5. Narayanan, G.V., et al., "Structural Tailoring/Analysis for Hypersonic Components (STAHYC) User Manual, NASA CR–187183, 1992.
6. Hopkins, D.A. and Chamis, C.C., "A Unique Set of Micromechanics Equations for High Temperature Metal Matrix Composites, NASA TM–87154, 1985.
7. Chamis, C.C. and Hopkins, D.A., "Thermoviscoplastic Nonlinear Constitutive Relationships for Structural Analysis of High Temperature Metal Matrix Composites," NASA TM–87291, 1985.
8. Chamis, C.C., Murthy, P.L.N., and Hopkins, C.A., "Computational Simulation of High Temperature Metal Matrix Composites Cyclic Behavior," NASA TM–102115, 1988.
9. Murthy, P.L.N., Hopkins, D.A., and Chamis, C.C., "Metal Matrix Composite Micromechanics: In-situ Behavior Influence on Composite Properties," NASA TM–102302, 1989.
10. Chamis, C.C., Caruso, J.J., and Lee, H.J., "METCAN Verification Status," NASA TM–103119, 1990.
11. Saravanos, D.A., Murthy, P.L.N., and Morel, M., "Optimal Fabrication. Process for Unidirectional Metal Matrix Composites: A Computational Simulation," NASA TM–102559, 1990.

12. Morel, M., and Saravanos, D.A., "Concurrent Micromechanical Tailoring and Fabrication Process Optimization for Metal-Matrix Composites," NASA TM–103670, 1990.

13. Morel, M., Saravanos, D.A., and Chamis, C.C., "Interphase Layer Optimization for Metal Matrix Composites with Fabrication Considerations," NASA TM–105166, 1991.

Table 1: HITCAN Capabilities for Hot Composite Structures

Type of analysis ↓ / Type of structure →	Beam	Plate	Ring	Curved panel	Built-up structure
Static	tested	tested	tested	tested	tested
Buckling [a]	tested	tested	tested	tested	tested
Load stepping	tested	tested	tested	tested	tested
Modal (natural vibration modes) [b]	tested	tested	tested	tested	tested
Time-domain	-	-	-	-	-
Loading					
Mechanical	tested	tested	tested	tested	tested
Thermal	tested	tested	tested	tested	tested
Cyclic	-	-	-	-	-
Impact	-	-	-	-	-
Constitutive models [c]					
$P = \text{constant}$	tested	tested	tested	tested	tested
$P = f(T)$ (temperature dependence)	tested	tested	tested	tested	tested
$P = f(\sigma)$ (stress dependence)	tested	tested	tested	tested	tested
$P = f(\dot{\sigma})$ (stress rate dependence)	tested	tested	tested	tested	tested
$P = f(t)$ (creep)	-	-	-	-	-
$P = f(T, \sigma, \dot{\sigma})$ (combination)	tested	tested	tested	tested	tested
$P = f(T, \sigma, \dot{\sigma}, t)$ (creep combination)	-	-	-	-	-
Fiber degradation	tested	tested	tested	tested	tested
Fabrication-induced stresses	tested	tested	tested	tested	tested
Ply orientations [d]					
Arbitrary	tested	tested	tested	tested	tested

(a) Tested 1 buckling mode
(b) Tested 4 vibration modes

(c) Constitutive models: Notation
P: Material properties
T: Temperature
σ: Stress
$\dot{\sigma}$: Stress rate
t: Time

(d) Tested 3 ply orientations:
Unsymmetric: $(0/\pm45/90)$
Symmetric: $(0/45)_s$
Balanced: $(0/90)_s$

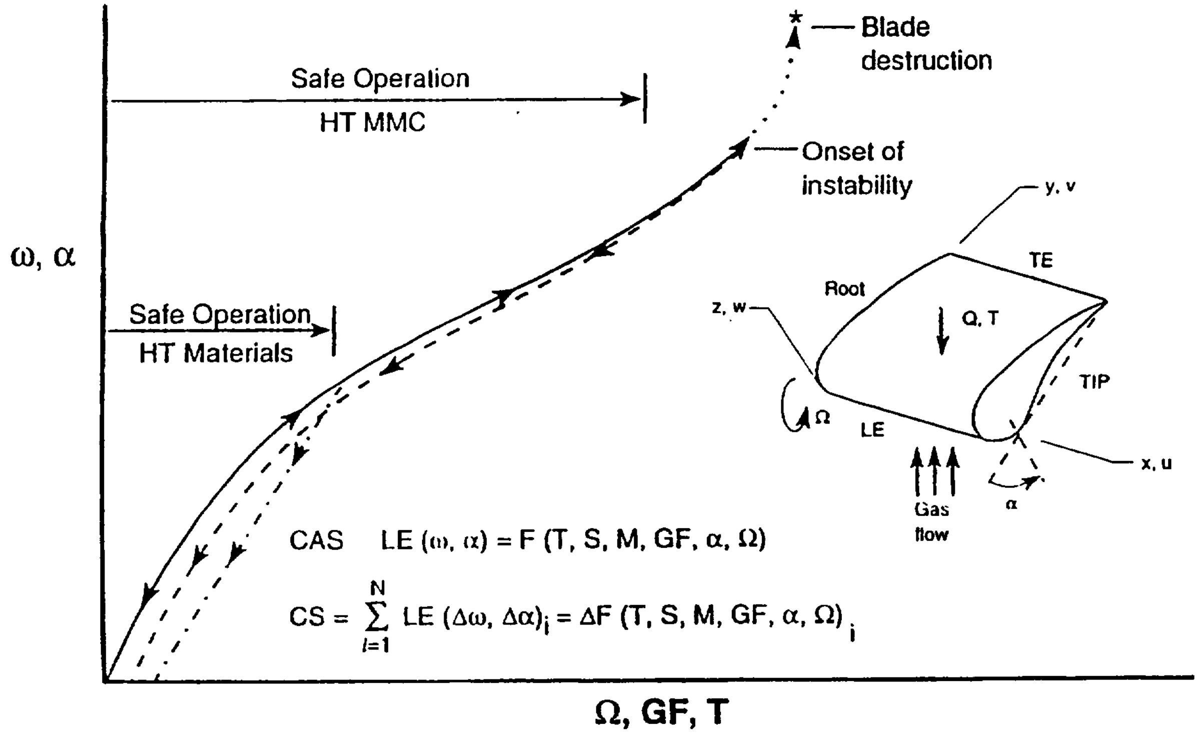


Figure 1.—Computer aided solution (CAS) versus computational simulation (CS).

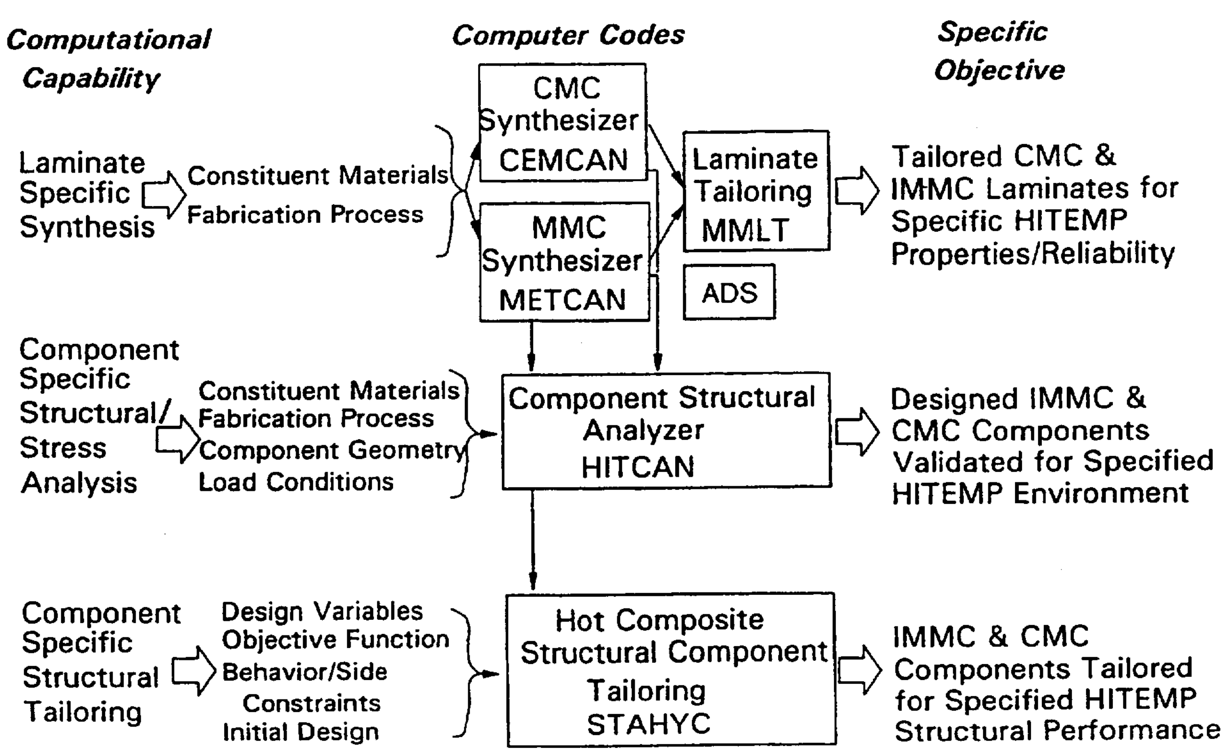


Figure 2.—Hierarchical computational simulation/tailoring of hot composite laminates/structures.

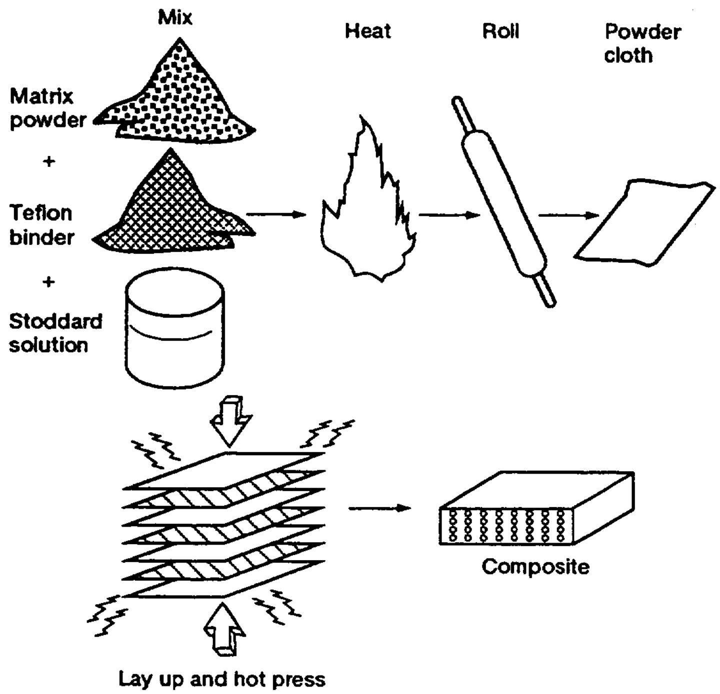


Figure 3.—Metal-matrix composite fabrication process.

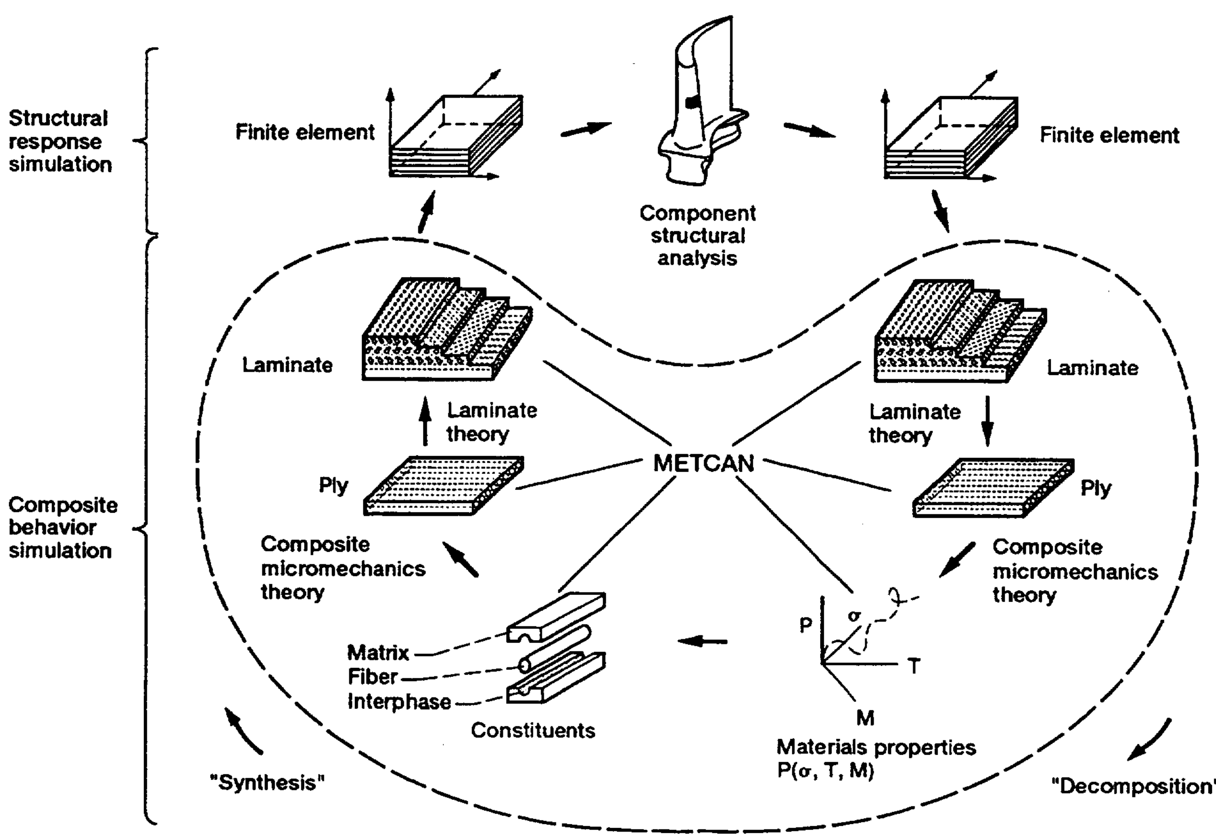
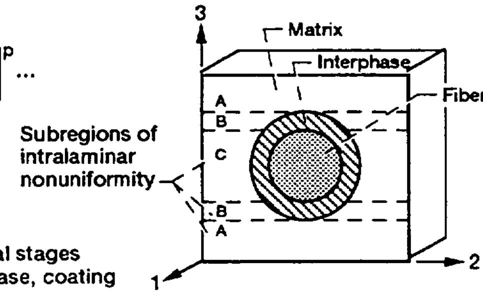


Figure 4.—METCAN (Metal Matrix Composite Analyzer) for the computational simulation of high temperature metal matrix composites behavior.

$$\frac{P}{P_O} = \left[\frac{T_F - T}{T_F - T_O}\right]^{1/2} \left[\frac{S_F - \sigma}{S_F - \sigma_O}\right]^{l} \left[\frac{\dot{S}_F - \dot{\sigma}}{\dot{S}_F - \dot{\sigma}_O}\right]^{m} \left[\frac{\dot{T}_F - \dot{\sigma}}{\dot{T}_F - \dot{\sigma}_O}\right]^{n} \left[\frac{R_F - R}{R_F - R_O}\right]^{p} \cdots$$

$$\cdots \left[1 - \frac{\sigma_M N_M}{S_F N_{MF}}\right]^{r} \left[1 - \frac{\sigma_T N_T}{S_F N_{TF}}\right]^{s} \left[1 - \frac{\sigma t}{S_F t_F}\right]^{u} \cdots$$



Rationale:

- Gradual effects during most range, rapidly degrading near final stages
- Representative of the in situ behavior for fiber, matrix, interphase, coating
- Introduction of primitive variables (PV)
- Consistent in situ representation of all constituent properties in terms of PV
- Room-temperature values for reference properties
- Continuous interphase growth
- Simultaneous interaction of all primitive variables
- Adaptability to new materials
- Amenable to verification inclusive of all properties
- Readily adaptable to incremental computational simulation

Notations:

P – property; T – temperature; S – strength; σ – stress; R – metallurgical reaction; N – number of cycles: t – time; over dot – rate; subscripts: O – reference; F – final; M – mechanical; T – thermal

Figure 5.—Multi-factor interaction model (MFIM) for In Situ constituent materials behavior.

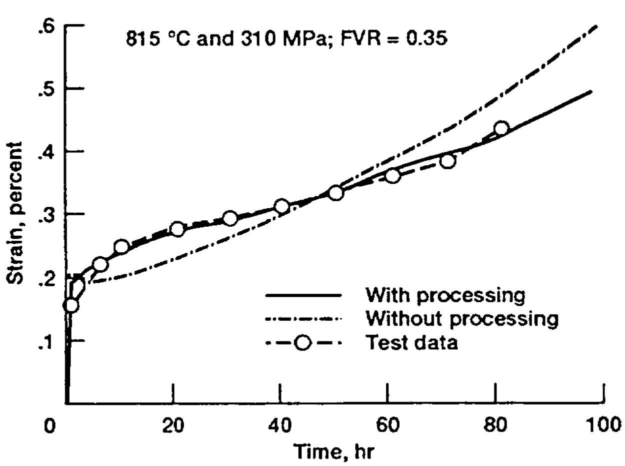


Figure 6.—Effect of processing on the creep behavior of [0] SCS6/Ti-24Al-11Nb composite.

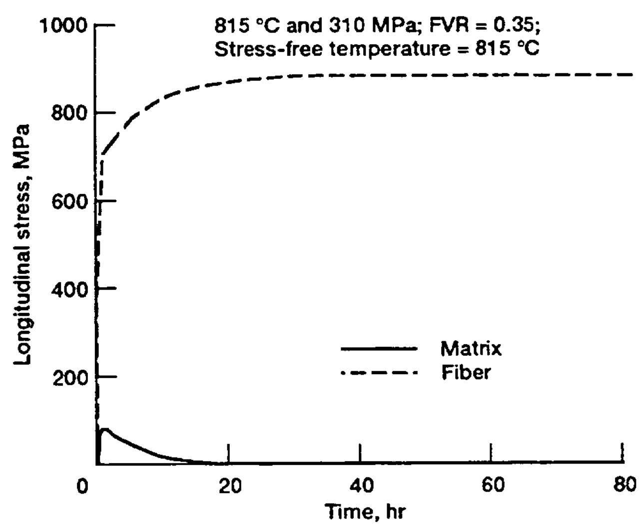


Figure 7.—Microstresses in [0] SCS6/Ti-24Al-11Nb composite.

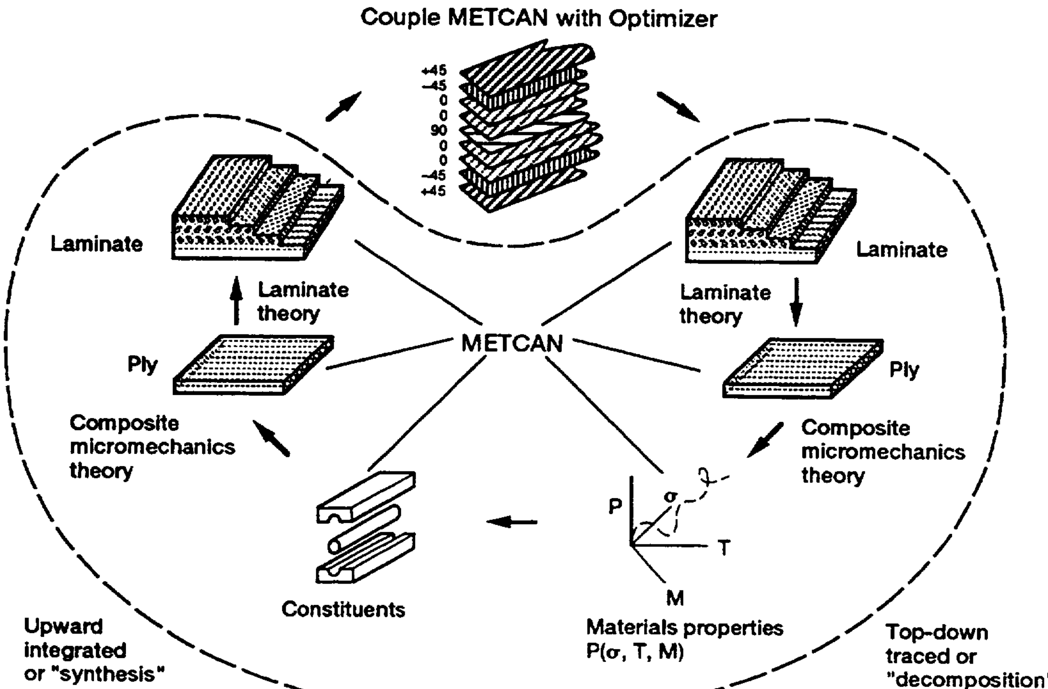


Figure 8.—Metal matrix laminate tailoring (MMLT).

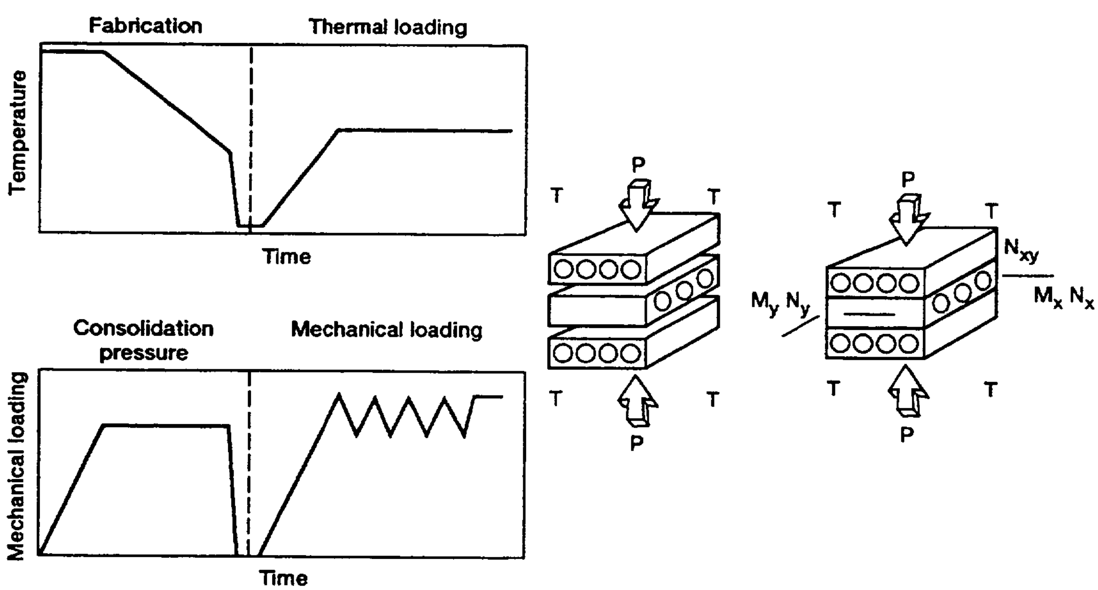


Figure 9.—Typical fabrication and thermomechanical cycle of metal matrix laminates.

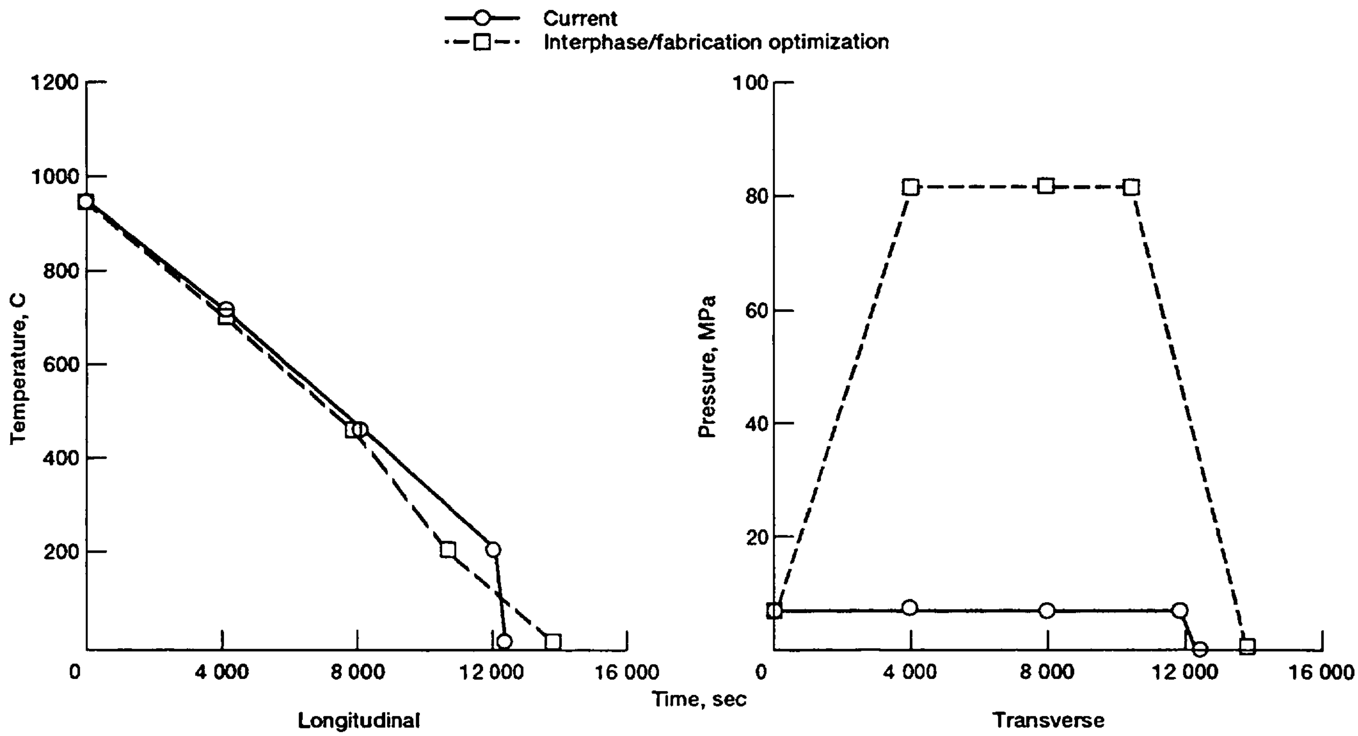


Figure 10.—Optimum and current cool-down phase for SiC/Ti15-3-3-3.

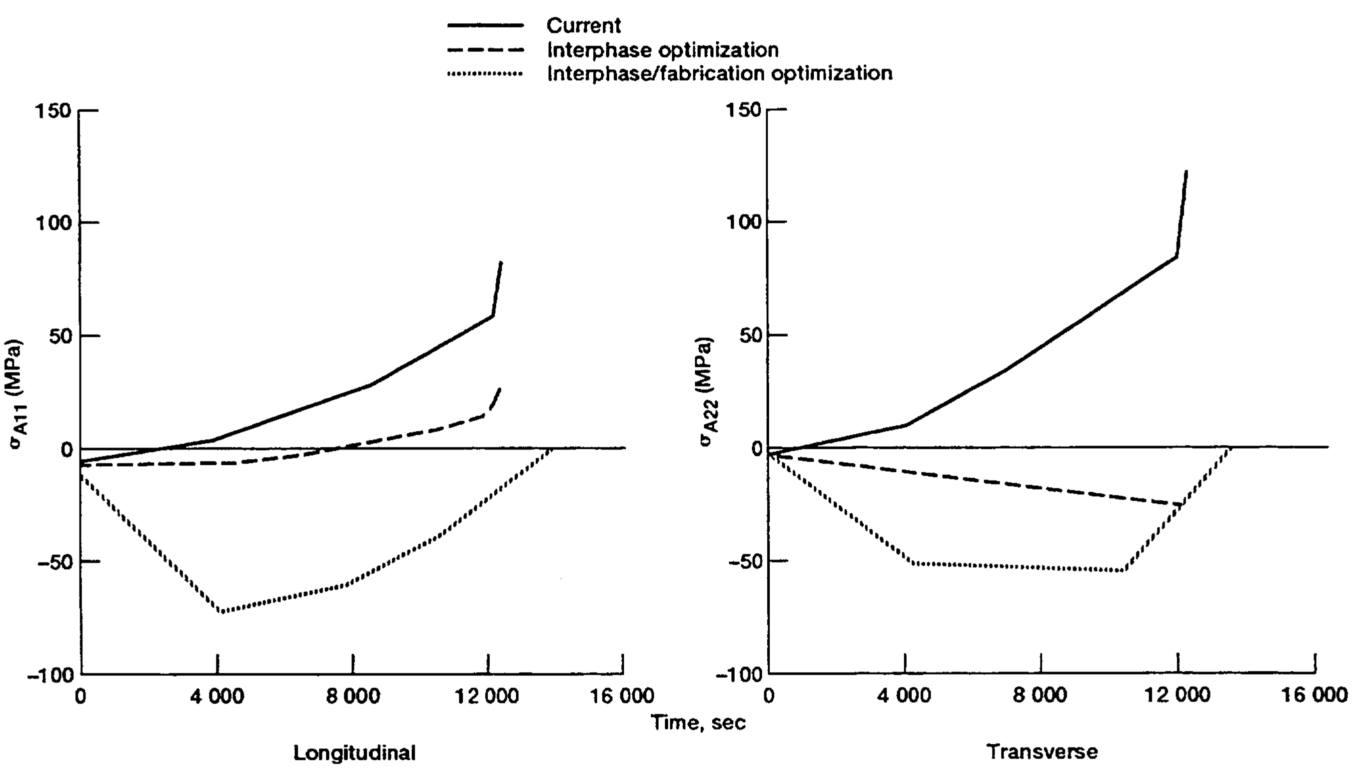


Figure 11.—Matrix microstresses developed during the cool-down phase of SiC/Ti15-3-3-3.

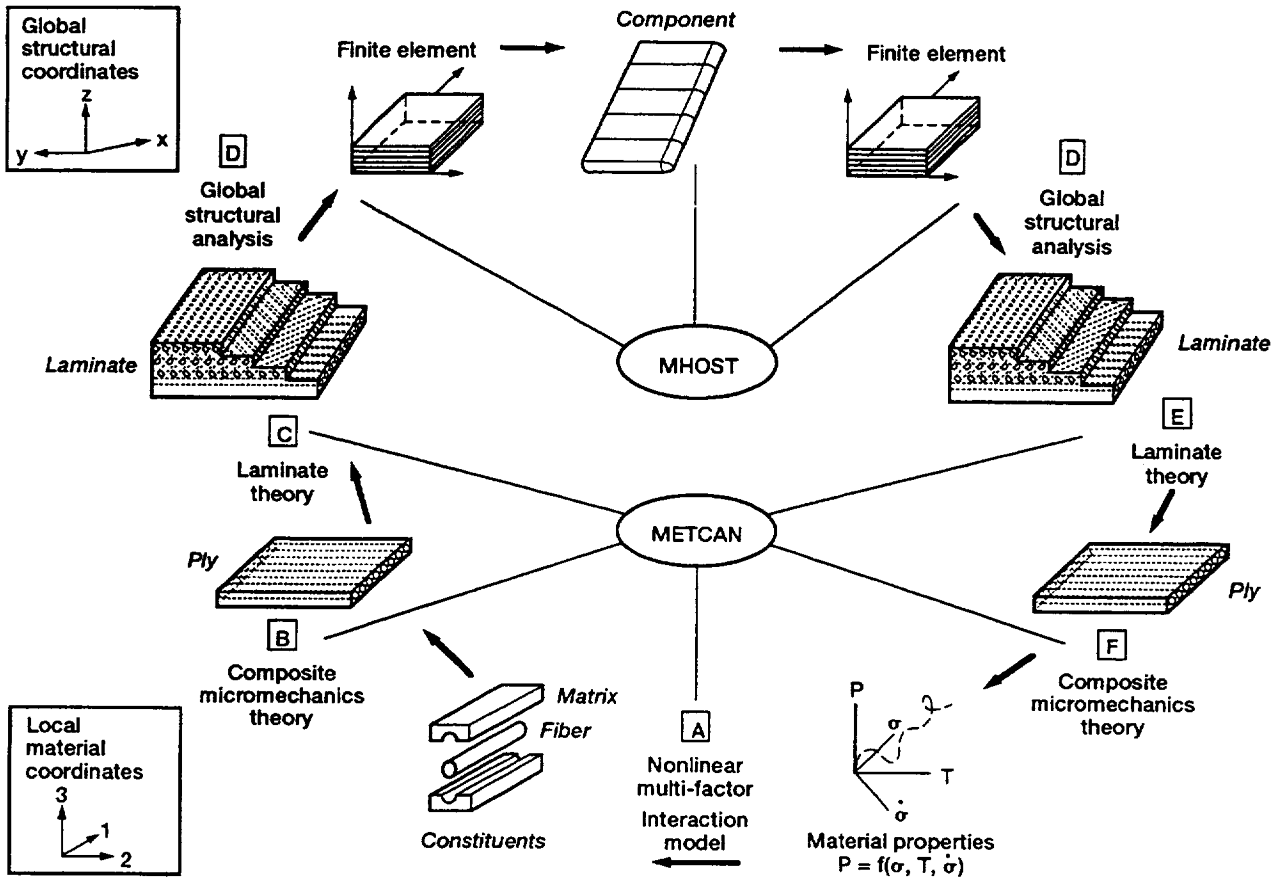


Figure 12.—HITCAN: an integrated approach for hot composite structures.

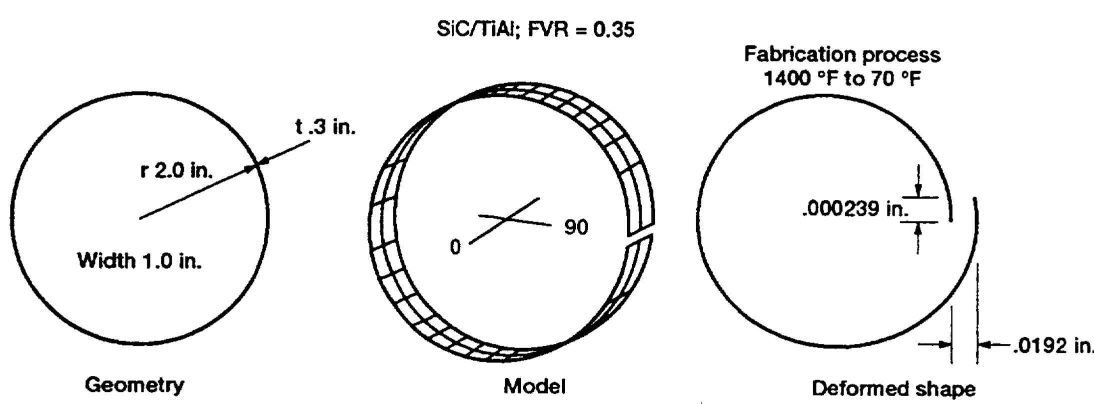


Figure 13.—HITCAN nonlinear analysis of ring with slit.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1993	Technical Memorandum

4. TITLE AND SUBTITLE

Hierarchical Nonlinear Behavior of Hot Composite Structures

5. FUNDING NUMBERS

WU-505-63-5B

6. AUTHOR(S)

P.L.N. Murthy, C.C. Chamis, and S.N. Singhal

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E-7947

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM-106229

11. SUPPLEMENTARY NOTES

Prepared for the First Joint SES, ASME, and ASCE Meeting, Charlottesville, Virginia, June 7-9, 1993. P.L.N. Murthy and C.C. Chamis, NASA Lewis Research Center, Cleveland, Ohio 44135, and S.N. Singhal, Sverdrup Technology, Inc., Lewis Research Center Group, 2001 Aerospace Parkway, Brook Park, Ohio 44142. Responsible person, C.C. Chamis, (216) 433-3252.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 39

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Hierarchical computational procedures are described to simulate the multiple scale thermal/mechanical behavior of high temperature metal matrix composites (HT-MMC) in the following three broad areas: (1) Behavior of HT-MMCs from micromechanics to laminate via METCAN (Metal Matrix Composite Analyzer), (2) tailoring of HT-MMC behavior for optimum specific performance via MMLT (Metal Matrix Laminate Tailoring), and (3) HT-MMC structural response for hot structural components via HITCAN (High Temperature Composite Analyzer). Representative results from each area are presented to illustrate the effectiveness of computational simulation procedures and accompanying computer codes. The sample case results show that METCAN can be used to simulate material behavior such as the entire creep span; MMLT can be used to concurrently tailor the fabrication process and the interphase layer for optimum performance such as minimum residual stresses; and HITCAN can be used to predict the structural behavior such as the deformed shape due to component fabrication. These codes constitute virtual portable desk-top test laboratories for characterizing HT-MMC laminates, tailoring the fabrication process, and qualifying structural components made from them.

14. SUBJECT TERMS

Computational simulation; Computer-aided solution; Computer code; Creep; Fabrication; High temperature; Hot; Interphase; Laminate theory; Material behavior; Metal matrix composites; Macromechanics; Micromechanics; Nonlinear analysis; Optimization; Residual stress; Structural response; Tailoring

15. NUMBER OF PAGES

20

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102